PHYSICAL AND TAPPING CHARACTERISTICS OF MURUCHI (Borassus aethiopum) FLOUR AS INFLUENCED BY MOISTURE CONDITION

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Abstract
The influence of moisture content on physical properties and tapping behavior of ‘muruchi’ flour was determined with a view to exploring the possibility of efficient handling at industrial scale. The properties measured were geometric mean diameter, geometric standard deviation, estimated surface area and number of particles per unit gram, loose-filled bulk density and tapped bulk density. Experimental data were simulated using log-normal function to estimate maximum percent mass retained and maximum particle size, while in finite compressibility by tapping and degree of difficulty of tapping were estimated using Sone’s model. Moisture content had a significant influence on the physical properties of the flour. The geometric mean diameter of particle by mass decreased linearly from 286 to 234 µm as moisture content increased from 6.32% to 10.96% (db) while estimated total surface area and number of particles per gram increased linearly from 396.5 to 582.6 cm², and 515,188 to 1,675,732 particles respectively. The particle size ranged between 75 and 400 µm, where 300 µm particle size was the modal particle size. The estimated maximum percent mass retained and maximum particle size decreased as moisture content increased. Loose-fill bulk density and tapped density had highest and lowest values of 462.46 and 425.35 kg/m³ and 600.71 to 518.53kg/m³ at 6.32% and 10.96% moisture contents respectively. As moisture content increased from 6.32% to 10.96% (db) the maximum volume reduction ratio by tapping decreased from 0.2302 to 0.1797. The infinite compressibility by tapping decreased as moisture content increased while the degree of difficulty of tapping did not show any definitive variation with moisture variation.

Keywords: ‘muruchi’ flour, geometric mean diameter, loose-filled bulk density, tapped density, compressibility, moisture content

1. Introduction
The hypocotyl of a young shoot of Borassus aethiopum is a fleshy and starchy edible vegetative part that is commonly cultivated in the savanna areas of West African countries. This young shoot is known in Nigeria among Hausa and Fulani as ‘muruchi’ and ‘bhachi’ respectively. It is consumed when cooked and ground into flour for preparation into various food products using local means. ‘Muruchi’ flour is a potential source of starch that is rich in carbohydrate 86.9% and appreciable nutritional value (Michel et al., 2013). Substantial research efforts have been devoted to study the physico-chemical and functional properties of this native flour aimed at understanding its potential application in starch and pharmaceutical industries (Ali et al., 2010; Aguzue et al., 2013; Michel et al., 2013). However, for this native flour to be efficiently handled at industrial level, knowledge of its physical properties and compression behavior is important to the design of handling, packaging and storage systems, and during process operations such as flow in hoppers, mixing and compression. Particle size is one of the physical properties of powdered materials that play an important role in unit operations such as milling, mixing, hydrating, extruding and pneumatic handling (Barbosa-
Ca’novas and Yan, 2003). Particle size parameters such as geometric mean diameter and geometric standard deviation represent the fineness of powder and are used to estimate number of particles and total surface area of a unit mass (ASABE, 2006). During fluidized bed drying and pneumatic conveying of powdered materials, number of particles and total surface areas can influence the performance of the process significantly. Another important physical property of flour is bulk density. Bulk density is the measure of quantity of bulk material in mass per unit volume. The bulk density of powdered material increases significantly due to vibration and tapping during handling and transportation or due to normal load during storage (Barbosa-Canovas and Yan, 2003; Emami and Tabil, 2008). Moisture content is an important component of food material that influences physical properties (Mohsenin, 1986) and the operational control, efficiency, and energy consumption of processing machines large depend on it (Aviara et al., 1999).

In order to fully characterize powdered materials, researchers simulate experimental data by using appropriate mathematical models to estimate significant parameters. Characteristic size of a distribution and measure of size distribution spread are the common parameters found in particle size distribution functions. For instance, Yang et al. (1996) used log-normal function to estimate the median size and standard deviation of alfalfa grind. Chevanan et al. (2010) estimated the infinite compressibility by tapping and degree of difficulty of tapping for chopped switch grass, wheat straw and corn stover using Sone’s model. The physical properties and tapping characteristics of several agricultural powdered materials have been investigated experimentally and their results were simulated. The physical properties of corn and soybean meal, coconut flours, modified potato starch, and native starches of maize, wheat and potato have been reported by Molenda et al. (2002), Manikantan et al. (2015), Stasiak et al. (2014) and Stasiak et al. (2013) respectively. However, there is no study carried out on the physical properties of muruchi flour and how moisture content influenced them.

Thus, the objectives of this research work were to: determine the influence of moisture content on geometric mean diameter and geometric standard deviation by mass, number of particles and total surface area per unit weight, bulk and tapped densities of muruchi flour; and simulate its particle size distribution and compression by tapping using log-normal function and Sone’s model respectively.

2. Materials and Methods

2.1. Sample Preparation

One hundred kg of young shoots of Borassus aethiopum were procured from Hong town market in Hong Local Government of Adamawa State, Nigeria. After sorting out damaged ones, the remaining samples were de-fibred using knives chopped into slices and then dried under ambient condition until no further reduction in mass occurred. This took about two weeks. Locally fabricated hammer mill with 2 mm screen size was used to grind the dried slices. Three samples of flour weighing 10 g each were collected and their moisture contents were determined using oven drying method (Jayas and Cenkowski, 2006). The average moisture content was calculated.
to be 6.32% (db). The remaining flour (12 kg) was then divided into three portions using spinning method and two portions were conditioned into different moisture content levels of 8.55%, and 10.96% (db). The conditioned samples were sealed in containers and kept in refrigerator at 5°C for 5 days for the moisture to reach equilibrium within the flour. The amount of water that was added to raise the moisture content level of each sample was calculated using Equation (1):

\[ Q = \frac{w_i(m_f - m_i)}{(100 - m_f)} \]  

where: \( Q \) is the quantity of water added in g, \( w_i \) is the weight of sample at initial moisture content in g, \( m_i \), and \( m_f \) is the final moisture content, %.

2.2. Experimental Tests and Design

Sieving test was carried out using the ASABE (2006) standard method. The set of sieves used for the test have same frame diameters of 200 mm and sieve wire-cloth openings that range from 44 to 2000 μm. A sieve shaker held the set of 10 sieves and a pan arranged in descending order of opening. A charge of 100 g at specific moisture content was initially placed on the top sieve and a small rubber ball. The entire setup was then allowed to shake for 15 minutes to reach the endpoint of the sieving process. After shaking, each sieve unit was weighed to record the amount of material in gram(s) left on it.

The loose bulk density and tapped density were measured using the USP (2012) standard method. This involved passing sample through a sieve of 2 mm to fill a dry 100 ± 1 ml graduated cylinder placed 2 cm below the sieve and carefully leveling the flour without tapping or compressing. The unsettled apparent volume \( (V_o) \) was read to the nearest graduated unit. The tapping test was carried out by securing the filled cylinder in the holder of a tapping apparatus capable of dropping from a height of 10 mm. The tapped volumes after 10, 250, 500, 750, 1000 and 1250 taps on the same sample were recorded.

Completely randomized design was used in all the tests as the experimental design. Samples at all moisture contents were randomly assigned to the sequence of test runs during tests. Each test at particular moisture content was replicated three times.

2.3. Data Analysis and Simulation

The size of particles was expressed in terms of geometric mean diameter and geometric standard deviation based on the assumption that particle sizes of powdered materials are logarithmic normally distributed (ASABE, 2006). The geometric mean diameter and geometric standard deviation were determined using Equations (2) and (3) respectively (ASABE, 2006; Wang et al. 1995):

\[ d_{gw} = \log^{-1} \left[ \frac{\sum_{i=1}^{n} w_i \log d_i}{\sum_{i=1}^{n} w_i} \right] \]  

\[ S_{gw} = \log^{-1} \left[ \frac{\sum_{i=1}^{n} w_i (\log d_i - \log d_{gw})^2}{2 \sum_{i=1}^{n} w_i} \right]^{\frac{1}{2}} \]
where: $d_{gw}$ and $S_{gw}$ are geometric mean diameter of particle and geometric standard deviation of particle by mass (μm) respectively, $W_i$ is mass of flour on $i^{th}$ sieve (kg), and $d_i$ is geometric mean diameter on the $i^{th}$ sieve. The graphical representation of particle size distribution of the flour was obtained by plotting its percentage mass retained against size of sieve openings. The experimental data of particle size distribution was simulated using log-normal function (Equation 4):

$$P_i = a_1 \times \exp \left(-0.5 \frac{\ln \left( \frac{x}{x_0} \right)}{b_1} \right)^2$$

(4)

where: $P_i$ is percentage mass retained on sieve size $x$; $a_1$ is maximum percent mass retain and $b_1$ is constant; $x_0$ is the maximum particle size.

The estimated total surface area, $A_{st}$, and number of particles, $N_i$, in a charge were calculated using Equations (5) and (6), respectively (Yang et al. 1996):

$$A_{st} = \frac{\beta_s \times W_i}{\beta_v \times \rho \times d_{gw}} \left[ 0.5 \times (\ln S_{gw})^2 \right]$$

(5)

$$N_i = \frac{W_t}{\beta_v \times \rho \times d_{gw}} \left[ 4.5 \times (\ln S_{gw})^2 \right]$$

(6)

where: $\beta_s$ and $\beta_v$ are shape factors for surface area and volume of particle respectively, $S_{ln}$ is geometric standard deviation in natural logarithm and $W_t$ is total mass of charge. The loose bulk density and tapped density were calculated by dividing the mass of the flour in the graduated cylinder by the uncompressed volume of the flour and tapped volume respectively. The index of the ability of the flour to flow was calculated using the compressibility index and Hausner ratio. The compression behavior of the flour with tapping was simulates using Sone’s model (Equation 7):

$$\frac{n}{\gamma_n} = \frac{1}{a_2 \times b_2} + \frac{n}{a_2}$$

(7)

where: $n$ is the number of tapping, $\gamma_n$ is volume reduction ratio, $a_2$ and $b_2$ are constants.

Simple descriptive statistical analysis was used to report averages and standard deviations of the experimental data. Data obtained were subjected to ANOVA to determine the levels at which the effects of moisture content were significantly different. Microsoft Excel software was used to plot graphs and carryout the statistical analysis.

3. Results and Discussion
3.1. Particle size and Particle Size Distribution
Table 1 presents the results of some physical properties of muruchi flour at moisture content levels of 6.32%, 8.55% and 10.96% (db), and the statistical significance of the variations. The geometric mean diameter by mass decreased as moisture content increased from 6.32% to
10.96% (db). The variation in moisture content of muruchi flour significantly influenced the geometric mean diameter. Lawal et al. (2016) reported an increase of geometric mean diameter by mass of baobab leaf powder with increase moisture content and attributed it to expansion of particle due to moisture absorption. The decrease of geometric mean diameter of muruchi flour as moisture content increase could be because finer particles absorb more moisture than their relatively coarser particles, and consequently the former would have relatively higher unit weight. The geometric standard deviation by mass did not show any significant variation with increase in moisture content. The relationship between moisture content and geometric mean diameter by mass of muruchi flour was found to be linear and can be represented with the following (Equation 8):

$$d_{gw} = 356.4 - 11.1M \quad (R^2 = 0.8865)$$

where: M is moisture content.

Table 1. Geometric mean diameter, geometric standard deviation, estimated surface area of and number of particles per gram, Loose-filled bulk density, tapped bulk density, compressibility index, and Hausner ratio for muruchi flour at moisture content range between 6.32% and 10.96% (db).

<table>
<thead>
<tr>
<th>Parameter</th>
<th>6.32% (wb) mc</th>
<th>8.55% (wb) mc</th>
<th>10.96% (wb) mc</th>
<th>F-value</th>
<th>P-value</th>
</tr>
</thead>
<tbody>
<tr>
<td>Geometric mean diameter of particle by mass, d_{gw} (μm)</td>
<td>286 (6.5)</td>
<td>263 (12)</td>
<td>234 (7.6)</td>
<td>23.4</td>
<td>0.00146</td>
</tr>
<tr>
<td>Geometric standard deviation of particle diameter by mass, S_{gw} (μm)</td>
<td>161 (17)</td>
<td>164 (9.6)</td>
<td>158 (4.3)</td>
<td>0.236</td>
<td>0.796</td>
</tr>
<tr>
<td>Estimated surface area, Ast (cm^2/g)</td>
<td>396.5 (22)</td>
<td>474.4 (21)</td>
<td>582.6 (16)</td>
<td>63.48</td>
<td>0.0000</td>
</tr>
<tr>
<td>Number of particles per gram, N_t</td>
<td>515,188</td>
<td>883,098</td>
<td>1,675,732</td>
<td>34.82</td>
<td>0.0005</td>
</tr>
<tr>
<td>(178,640)</td>
<td>(105,704)</td>
<td>(218,658)</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Loose bulk density (kg/m^3)</td>
<td>462.46 (3.7)</td>
<td>448.3 (6.67)</td>
<td>425.35 (8.31)</td>
<td>9846</td>
<td>0.0000</td>
</tr>
<tr>
<td>Tapped density (kg/m^3)</td>
<td>600.71 (4.83)</td>
<td>572.79 (8.53)</td>
<td>518.53 (10.12)</td>
<td>3537</td>
<td>0.0000</td>
</tr>
<tr>
<td>Compressibility index</td>
<td>23.20</td>
<td>21.73</td>
<td>17.97</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Hausner ratio</td>
<td>1.300</td>
<td>1.280</td>
<td>1.220</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

Numbers in parentheses are standard deviation

The graphical plots of the distributions of the percent mass retained on each test sieve for muruchi flour at different moisture content levels are presented in Figure 1. The plots in Figure 1 show skewness similar to those reported for baobab leaf powder (Lawal et al., 2016). Most
particles, 89%, were in the range of 75 to 400 μm for the samples. It can be seen from Figure 1 that particle size of 300 μm had the maximum percent mass retained of 49%, 41.6%, and 33.5% at moisture content of 6.32, 8.55, and 10.96% (db) respectively. Figure 2 presents the distributions of particle size plotted on log scaled abscissa and log-normal distribution function plots fitted to the experimental data. The $R^2$ value of log-normal distribution function (0.7682 to 0.9048) indicated a good fit to the experimental data. Equations 9 to 11 present the log-normal estimate of percent mass retained. The estimated maximum percent mass retained, $a_1$ and maximum particle size, $x_0$ decreased with increased in moisture content.

$$P_{6.32} = 52.23 \exp^{-0.5 \left( \frac{\ln(x)}{0.1944} \right)^2} \quad (R^2 = 0.7682)$$ (9)
Increase in moisture content significantly increased the estimated surface area per gram of muruchi flour (Table 1). The number of particles per gram of muruchi flour was also significantly increased as the moisture content increased. The increase in estimated surface area could be due to volumetric expansion of the particles with moisture content increase or increase in number of particles due to increased tendency of particle breakage during sieving as moisture content of flour increased. The result of regression analyses showed that there is linear relationship between moisture content and the estimated surface area and number of particles per gram of muruchi flour (Equation 12 and 13):

$$A_{st} = 276M - 1394.6 \quad (R^2 = 0.9422)$$

$$N_{C} = 251175M - 1137946 \quad (R^2 = 0.8893)$$

### 3.3. Bulk Density and Tapping Characteristics

The variation of loose-filled bulk density was significantly influenced by change in moisture content of muruchi flour (Table 1). It can be observed from Table 1 that the loose-filled bulk density decreased as the moisture content increased. Wang et al. (1995), Stasiak et al. (2014) and Manikantan et al. (2015) reported similar trends for bulk densities of soybean meal, potato starch and coconut flours as their moisture content increase respectively. This could be attributed to particle expansion and reduction in void space as moisture content increases. A significant relationship similar to loose-filled bulk density was also observed between tapped bulk density and moisture content. The linear relationship between moisture content and the bulk densities can be expressed using regression (Equations 14 and 15) for loose-fill bulk density and tapped density respectively:

$$\rho_{lb} = 514 - 8.01M \quad (R^2 = 0.8619)$$

$$\rho_{t} = 717 - 17.8M \quad (R^2 = 0.9654)$$

where: $\rho_{lb}$ and $\rho_{t}$ are loose-fill density and tapped density (kg/m$^3$) respectively.

The measures of the flour to be compressed by tapping and inter-particulate interaction were influenced by moisture content. It can be seen from Table 1 that the compression index (settleability) of the particles improves at lower moisture content, while Hausner ratio (flowability) of the particles becomes poor at lower moisture content.

The graphical representation of the relationship between volume reduction ratio of muruchi flour and number of taps is shown in Figure 3. The maximum volume reduction ratios were reached by 1000 taps for all samples at 6.32%, 8.55%, and 10.96% (db) moisture content. The maximum volume reduction ratios observed were in the order of 0.23 at 6.32% (db), 0.217 at 8.55% (db), and 0.1796 at 10.96% (db) moisture contents. The decrease in volume reduction ratio as moisture
content increase could be an indication of reduced void space at higher moisture levels which was observed with the loose-filled bulk density.

Sone’s plots fitted into experimental data plots for samples at 6.32%, 8.55%, and 10.96% (db) moisture contents are presented in Figure 4. The high $R^2$ values of 0.9999 at each moisture content level indicate that Sone’s model simulated the experimental data very well. The values for the parameters of Sone’s model within the moisture content domain are presented Equation (16) to (18). The parameter representing the infinite compressibility by tapping, $a_2$ was significantly reduced from 0.234 to 0.183 as moisture content increased from 6.32% to 10.96% (db). It can be observed that Sone’s infinite compressibility expressed in percentage was slightly higher than the compressibility index by 0.36%, 0.28%, and 0.15% for 6.32%, 8.55%, and 110.96% (db) moisture contents respectively. The difference between Sone’s infinite compressibility and compression index could represent the percentage void remaining in the tapped flour. The second parameter of Sone’s model expressing the degree of difficulty of tapping, $b_2$, decreased with moisture content increase from 6.32% to 8.55% while increased at 10.96%.
4. Conclusion
The influence of moisture content on the physical and compression characteristics of *muruchi* flour was investigated in this study. The following conclusions can be drawn from the study:

1. Moisture content had a significant effect on the selected physical and tapping characteristics of *muruchi* flour.
2. The estimated total surface area and number of particles per gram increased from 396.5 to 582.6 cm$^2$/g and 515,188 to 1,671,732 as moisture content increased from 6.32% to 10.96% (db) while geometric mean diameter, loose-fill bulk density and tapped density decreased.
3. The maximum volume reduction ratio by tapping samples decreased as moisture content increased while the maximum volume reduction ratios observed were in the order of 0.23 at 6.32% (db), 0.217 at 8.55% (db), and 0.1796 at 10.96% (db) moisture contents.

References


